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VIA HAND DELIVERY

Mr. Walter D. Strack
Wireless Telecommunications Bureau
Federal Communications Commission
Room 5202F
2025 M Street, N.W.
Washington, D.C. 20554

Re: CC Docket No. 95-185
WRITTEN EX PARTE PRESENTATION

Dear Mr. Strack:

At the request of Alexandra Wilson of Cox Enterprises, Inc. ("Cox"), I have enclosed certain materials that were used in the preparation of Cox's recent submissions to the Commission regarding the actual costs of terminating traffic on local telephone networks. These materials are as follows:

(1) "Incremental Costs of Telephone Access and Local Usage," by Bridger M. Mitchell, published by The RAND Corporation;

(2) "The Use of Econometric Analysis in Estimating Marginal Cost," by Lewis J. Perl and Jonathan Falk of National Economic Research Associates, Inc.;

(3) The testimony of Paula L. Brown on behalf of NYNEX in Massachusetts DPU Docket 93-125; and

(4) Cox's recalculation of NYNEX's costs of termination, based on the data provided in Ms. Brown's testimony.

In accordance with the requirements Section 1.1206(a) of the Commission's Rules, two copies of this letter and the enclosures are being submitted to the Secretary's office on this date.

0+2

Please inform me if any questions should arise in connection with this letter.

Respectfully submitted,

J.G. Harrington

JGH/taf
Attachments

RAND/R-3909-ICTF

Incremental Costs of Telephone Access and Local Use
Mitchell

Incremental Costs of Telephone Access and Local Use

Bridger M. Mitchell

RAND

The research described in this report was supported by a grant from GTE and Pacific Bell and guided by the Incremental Cost Task Force, with members from GTE, Pacific Bell, the California Public Utilities Commission, and The RAND Corporation.

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Incremental Costs of Telephone Access and Local Use

Bridger M. Mitchell

July 1990

Prepared for the
Incremental Cost Task Force

RAND

PREFACE

This report describes the empirical results of an investigation into the incremental costs of local telephone service. The methodology and cost estimates provide a broad-gauge assessment of the incremental costs of supplying local telephone service in conditions typical of California markets.

This research should contribute to generic inquiries into telephone pricing and regulation; it is not designed to yield findings for specific markets or rate cases. It should be of interest to public officials concerned with telephone ratemaking and regulation, to personnel of telecommunications firms responsible for investment planning, marketing, and pricing, and to others concerned with public policy for telecommunications and regulated utilities.

The study was supported by a joint research grant to The RAND Corporation from GTE and Pacific Bell. The project was guided by an Incremental Cost Task Force, with members from GTE, Pacific Bell, the California Public Utilities Commission, and RAND.

Preliminary versions of this study were presented at the Twentieth Annual Conference of the Institute of Public Utilities, Michigan State University, December 5–7, 1988, at Williamsburg, Virginia; at the industry forum on Telecommunications Costing in a Dynamic Environment, BellCore and Bell Canada, April 5–7, 1989, at San Diego, California; and at the Incremental Cost Conference, December 5–6, 1989, at Stanford University. Lehr (1990) summarizes the discussion from the Stanford conference.

Two companion reports by R. E. Park, *Incremental Costs and Efficient Prices with Lumpy Capacity: The Single Product Case* and *Incremental Costs and Efficient Prices with Lumpy Capacity: The Two Product Case*, analyze the role of incremental costs in pricing from a theoretical perspective.

SUMMARY

Telephone service has long been provided by franchised monopolies with prices regulated by public utility commissions. Rates for telephone service are traditionally calculated from fully distributed costs—formulas that first determine the total historical costs of the firm and then allocate those costs to individual products. As the total real costs of telephone service have fallen over time, these rate formulas have been revised to reduce the real price of local residential telephone service.

Marginal and incremental costs are well-established concepts in economics but are less familiar to local telephone companies and regulators. Incremental costs are the additional costs a firm will incur to expand service in the future. They measure the economic resources that must be expended—and therefore cannot be used elsewhere—to obtain a greater amount of telecommunications service.

Rates based on incremental costs tend to promote efficient use of scarce economic resources. This report develops a methodology for assessing the incremental costs of local telephone services and provides initial estimates of those costs for conditions typical of California markets served by the two major local exchange carriers—Pacific Bell and GTE. These estimates measure the average incremental costs of basic local telephone service—increased access to the telephone network and greater local network usage—in areas where telephone service is already available.

Related measures of incremental costs are relevant for other regulatory and business decisions such as assessing the conditions for entry into potentially competitive markets, weighing the costs and benefits of introducing a new technology, and measuring how the burden of telephone costs is shared among different consumers. If suitably extended, the methodology developed here can provide incremental cost estimates for such decisions.

We construct a small engineering-economic model of the three functional divisions of a local exchange: the local loop (the cables connecting subscribers to the switching point), the central office switch, and the interoffice transport facilities that link switches together.

Data for the model are drawn from a wide range of GTE, Pacific Bell, and other industry sources, and are aggregated and combined to obtain values representative of California conditions. The incremental cost estimates we report are not the actual values for a particular company or specific market.

In the local loop portion of the network, the incremental costs of additional lines increase directly with a subscriber's distance from the central switch. Incremental costs tend to be higher in smaller urban areas, in slowly growing communities, and in areas that do not have underground cables. Because the average distance of subscribers from the switching center varies widely among areas of similar population density, incremental costs may differ considerably for communities similar in other respects.

Modern local switches are special-purpose digital computers and associated equipment, much of which can be expanded modularly to serve increases in calling or more subscribers. Incremental costs for switching equipment are incurred when additional lines are added to the network, and also when the same number of lines is used more intensively at busy hours. The incremental costs of usage are higher in communities with a high proportion of calls between different switching centers.

Fiberoptic cables provide the principal facilities for transporting telephone traffic between switches. This capacity can be expanded to serve additional busy-hour usage at low incremental cost.

The local exchange network as a whole (local loop, switch, and interoffice transport) has average incremental costs for network access of some $53 to $158 per line annually across the three hypothetical communities examined—larger urban areas, approximately average communities, and small urban communities. The average incremental costs of usage are $3 to $11 per 100 seconds of originating usage during the busy hour each year, and an additional $1 per busy-hour call attempt per year.

Individual calling habits, as well as community characteristics, vary widely across California. At approximately average levels of telephone use, the combined incremental costs of additional residential lines (access plus average usage) range from $67–$93 annually in larger urban areas to $158–$179 in small urban communities. Incremental costs of additional business lines across the same communities range from $67 to $141 annually.

Telephone calls between subscribers not located in the same community require additional network switching. At busy hours the incremental costs of these calls are some two to four times the average incremental costs of local calls.

The incremental cost estimates in this study measure the extra costs of providing additional access and greater local usage. They exclude the large startup and overhead costs of the local exchange firm—major sunk costs that must be incurred once and recovered in the rates of a self-sufficient company—as well as nonrecurring expenses of establishing service, expenses associated with specific services, and overhead and administrative expenses.

Incremental cost methods can be applied to assess a wide variety of other telecommunications services. We examine the salient characteristics of four other services—centrex, private line, voice mail, and common-channel signaling—and identify functional components and sources of data that can be employed to extend the model developed in this study.

ACKNOWLEDGMENTS

We are indebted to many staff members at GTE and Pacific Bell for contributing their expertise and making data available for this study. Portions of the model used here are based on ideas previously developed in Pacific Bell's 1986 analysis of a local loop sample and GTE's ASTEC model of local exchange technology. We have also had the opportunity to review the SCIS and ACE costing models developed by Bell Communications Research.

The Incremental Cost Task Force, which coordinated this project, has contributed significantly to this research. Although we have been unable to incorporate all of its suggestions, we have benefited from many.

Ronald Braeutigam of Northwestern University, Timothy F. Bresnahan of Stanford University, and Frank Camm at RAND reviewed this report and made many helpful suggestions. Roger Noll of Stanford University served as moderator of a conference of industry and regulatory participants convened to discuss the methodology and findings developed during this project.

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I. INTRODUCTION

This report develops a methodology for assessing the incremental costs of local telephone services. It provides initial estimates of the incremental costs of access to the telephone network and of local calling, quantitative findings for conditions typical of markets served by California's two major local exchange carriers—Pacific Bell and GTE.

Incremental costs are concepts well established in economics but less familiar to local telephone companies and their regulators. Analysis of the incremental costs of telephone service—both methodology and actual calculations—has the potential to increase market efficiency, to improve the assessment of prospects for competitive entry into regulated markets and the benefits of adopting new technologies, and to determine the extent of service subsidies.

The methodology we have developed, which focuses on the incremental costs of expanding telephone service in communities already served by a local exchange company, can be used to assess the economic efficiency of telephone pricing.

If suitably extended, our incremental cost methodology can also help analyze the economic issues of competitive entry, adoption of new technology, and service subsidies. These extensions, however, lie outside the scope of the present study. Similarly, to apply our methodology to other geographic areas may require different values of the cost and demand parameters; we have used only California data here.

TRADITIONAL RATEMAKING

In the United States, telephone service has traditionally been provided by private, regulated monopolies. Prices have been set to recover the historically incurred total costs of these firms, including an allowed rate of return on invested capital. Today, for some products, principally intercity calls and terminal equipment, prices are increasingly determined by competitive markets. But in each community, a single local exchange company supplies access to the network, local calling, and other major services, and consumers pay prices set according to state public utility commission rules.

State regulators have traditionally based telephone rates on calculations of *fully distributed costs* (FDC). These formulas first determine the total historical costs of the firm, including an allowed return, and then allocate those costs to individual products (Braeutigam, 1980).

Such allocations apportion the total costs of a productive activity, or piece of capital equipment, on some basis (such as minutes of use) to the different products. If the price for each product is then set equal to its fully distributed cost, the firm's total revenue would appear to just equal total costs. In fact, consumers would adjust their demands for services as a result of the changes in prices; as a result, both total revenues and total costs would change. Prices set in anticipation of these demand adjustments can, however, yield total revenues equal to total costs.

For many years technological improvements have been lowering telecommunications costs more rapidly for long-distance services than for local services. In response, federal and state regulators have changed the cost allocation formulas several times, usually to increase the fraction of total costs allocated to intercity service. These policies have had the effect of reducing the real price of local service.

Although fully distributed costing has guided telephone rates, its formulas are not rigidly adhered to for all products. In specific markets, regulators have encouraged telephone companies to charge rates exceeding FDC to generate a "contribution" that permits other rates—particularly for local residential service—to be set below FDC, and, in some states, even below incremental costs.

INCREMENTAL COSTS AND RATEMAKING

Incremental costs are the additional costs a firm will incur to expand service in the future. They measure the economic resources that must be expended—and therefore cannot be used elsewhere—to obtain a greater amount of telecommunications service.

Rates based on incremental costs tend to promote efficient use of scarce economic resources. Broadly speaking, such rates encourage additional consumption when it is at least as valuable as its extra costs, but discourage users from purchasing services they value at less than their extra costs.

In regulated industries, setting rates *equal* to incremental costs is seldom possible. Significant economies of scale and scope mean that the extra costs of expanding service are frequently less than the average costs of service, so that if rates were set equal to incremental costs some portion of the total costs would not be recovered.

Nevertheless, incremental costs can be used as a *basis* for efficient prices. In this approach to ratemaking, prices are adjusted from incremental-cost levels to cover total costs while encouraging efficient resource use. The methods for doing this use information about

consumer demands as well as incremental costs (Baumol and Bradford, 1970).

Economic analysis of U.S. telephone rates has for some time found that, in broad terms, long-distance rates were substantially above incremental costs, that the volume of calling is sensitive to rates, and that lower rates would offer significant gains in efficiency (Rohlfs, 1979). The entry of new interexchange carriers into those intercity markets and the reduction in costs that regulators have allocated to interexchange access connections have already led to sizable gains in traffic and economic efficiency (Perl, 1988).

No comparable analysis of the economic efficiency of local telephone rates has been conducted, because of a lack of publicly available data from which to estimate incremental costs for local service. The research project of the California Incremental Cost Task Force is a significant effort to fill this gap.

MARKET ENTRY, NEW TECHNOLOGY, AND SERVICE SUBSIDIES

In addition to aiding ratemaking, the concept of incremental costs is central to analyzing three other topics. First, knowledge of incremental costs can help regulators assess the conditions for entry into potentially competitive markets and the nature of an incumbent firm's response. If rates are based on fully distributed costs, they may encourage selective entry into high-priced markets and prevent the incumbent from lowering its prices to the additional costs of expanding service. In contrast, if the regulated firm is permitted to set prices flexibly, but no lower than its incremental costs, consumers are assured that additional production is not occurring at the expense of other services.

Second, as technology advances and market conditions change, firms must choose whether to shift to a new method of production or continue to use existing equipment. New technology may expand the range of services and provide additional benefits, but it often entails large new investments. A cost-benefit analysis of such a decision compares these incremental outlays with the cost reductions and the new revenues they make possible.

Finally, incremental costs can clarify how the burden of telephone costs is shared among different consumers. If consumers' payments provide less revenue than the incremental cost of an entire service, those consumers receive an economic subsidy—one that is ordinarily financed by higher prices of other services (Faulhaber, 1975). Although regulatory proceedings frequently discuss "cross-subsidies" by comparing rates to fully distributed costs, these comparisons are misleading. The appearance and degree of a purported subsidy may reflect only the choice of a particular FDC formula.

LIMITATIONS

This report is limited to developing a methodology to assess the incremental costs of local exchange services and to constructing empirical estimates for California conditions. Our estimates, which measure the incremental costs of expanding service already supplied by an established local telephone company, provide information directly relevant to efficient pricing.

These estimates cannot be directly used to analyze market entry conditions, to assess the net benefits of new technology, or to test for the existence of rate subsidies. If suitably extended, however, this methodology can help address these issues as well. This report can be used as a starting point for future studies directed to such extensions.

We make several assumptions to keep the study tractable. We analyze only the major digital switching and digital trunking technologies—the technologies currently used to expand or replace older equipment—and we derive cost parameters from California operating companies' experience. Our empirical estimates are limited to basic access and usage services, or plain old telephone service (POTS in telephone parlance).

GTE and Pacific Bell have made a wide range of company data available for this study, and we have also had access to other industry cost information.[1] The cost parameters and incremental cost estimates we report are not the actual values for a particular company or market. We have aggregated and combined actual data from several sources to obtain values representative of California conditions.

PRODUCTION OF LOCAL TELEPHONE SERVICE

The market for local telephone service consists of the residents of an individual community and their potential demands for telephone communication with each other. The market is supplied, with limited exceptions, by a franchised monopoly firm—the local exchange carrier—subject to state commission regulation.

The dominant supply technology involves transporting subscribers' telephone calls over copper wires to a centrally located switching point,

[1]Appendix A summarizes the major sources of data we have used.

establishing computer-controlled connections to other subscribers, and transporting calls to neighboring switching points over high-capacity cables or microwave radio links (Fig. 1). These three activities are the functional divisions of local exchange production: the *local loop*, the *central office switch*, and *interoffice transport*. Together they constitute the local telephone network.

Ex ante, the local exchange firm could be imagined to examine alternative geographic configurations of the local telephone network. In principle, the choices of where to locate switching points, and how many switches to include in the network, would incorporate cost tradeoffs between shorter local loops and smaller and more numerous switches connected by larger amounts of interoffice trunking.

Most of the time, however, the choice of technology and the costs of serving additional demand are constrained by earlier decisions about where to place the physical facilities of the network—the underground cables and manholes, wire centers, and switching offices. Once these investments are incurred, they become sunk costs, and the incremental costs of expanding those facilities are almost always less than the total costs of a new configuration. Optimization decisions in telephone engi-

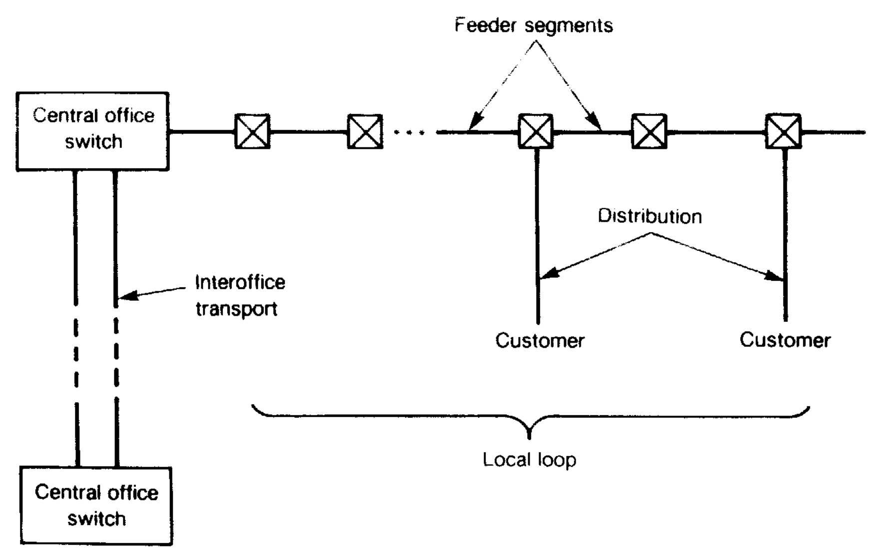


Fig. 1—Block diagram of local exchange

neering therefore focus on finding efficient cost configurations within each functional division of the network.

There are several alternative technologies for connecting subscribers to the telephone network. For example, pair gain systems carry several dozen subscribers' loops on just two pairs of wire; they substitute electronic signal processing for individual cable pairs. Remote switching units are smaller switching facilities that can be located close to a subcommunity of subscribers to reduce loop lengths at the cost of added switching and interswitch trunking. These systems, which currently serve a limited number of subscribers in California, are briefly considered in Appendix B.

Cellular radio represents a nonwire form of local loop, substituting radio transmission and switching points for copper pairs. Its use in mobile communication is growing rapidly. Fiberoptic cables are being used to distribute telephone calls to residential subscribers, in addition to video and other broadband services, in exploratory field trials. Perhaps one of these technologies will eventually become competitive with the costs of copper loops and be used to supply increased demand for access at fixed subscriber locations. However, we do not consider them in this study.

ECONOMIC CONDITIONS

The local exchange carrier is a multiproduct firm, supplying both access to the telephone network and local telephone calls (POTS), as well as access to long-distance carriers, business switchboard services, private lines, and various special services. These products require very capital-intensive methods of production. Long-lived plant and equipment and continual technological change result in a complex network in which different vintages of equipment operate side by side.

At the end of 1987, the 484 local exchange markets in California supplied by GTE and Pacific Bell had 13.8 million lines and some $3 billion in annual revenues from basic service. Investment in the local network, excluding interoffice facilities, was some $870 to $1250 per line. Table 1 summarizes several related statistics.

METHODOLOGY

Several analytic methods can be used to estimate incremental costs in the production of local exchange services:

Table 1

CALIFORNIA LOCAL EXCHANGE STATISTICS, 1987

Item	GTE	Pacific Bell
Local networks		
Number of exchanges	84	400
Number of wire centers	181	575
Lines		
Residence + business	2,800,000	11,043,000
Residence	2,244,000	7,944,000
Business	556,000	3,099,000
Per wire center	15,470	19,210
Growth, per wire center/year	538	863
Residence flat rate (excluding subscriber line charge)	$9.75/mo	$8.25/mo
Local revenues		
Residence, incl. msg units	$14.57/mo	$11.91/mo
Business	$39.42/mo	$32.86/mo
Book investment/line (excluding interoffice plant)		
Local loop	$796	$515
Local switch	$451	$354
Loop + switch	$1,247	$869

NOTE: An exchange is a geographic area defined for tariffing local calls. A wire center, usually housed in a central office, terminates local loops and connects them to a local switch.

1. With data from historical investment and expenditure accounts, one can use econometric methods to estimate production or cost functions for a cost-minimizing or profit-maximizing firm. This approach relies on actual investment decisions. But it is difficult to account for changes in technology over time, and the historical data cannot provide estimates of incremental costs of new methods of production. Econometric production and cost functions are most useful when data are available for a variety of output mixtures and levels using similar technology.
2. Using engineering planning models, one can investigate the resource requirements and costs of a specific technology, including new equipment not yet installed. By specifying different levels of output and operating conditions, one can simulate the investments and expenses the firm might incur to

satisfy each hypothetical set of circumstances. The resulting "pseudo-data" can then be analyzed with econometric methods, much as if they had been obtained from historical accounts. Although telephone operating companies use engineering models for local loop and local switch planning studies, extensive data requirements make such models difficult to use for generating local exchange pseudo-data.[2]

3. A third alternative is to construct an optimization model of a local exchange firm seeking to maximize profits (or minimize costs) subject to output requirements. Such a mathematical programming model would incorporate alternative local loop, switch, and interoffice transport technologies gleaned from basic engineering information. Marginal costs of individual products would then be obtained from the shadow prices of the output constraints. This approach has been used to analyze the relative pricing of local, state, and interstate calls (Littlechild and Rousseau, 1975), and suboptimizing models have been developed for design problems in specific loop and switch/transport networks (Okazaki, 1984; Roosma, 1985; Skoog, 1980; and Yoshida and Okazaki, 1985). However, no general models exist for optimizing resources among loop, switch, and interoffice transport components of the local exchange network that could be adapted to obtain marginal costs of access and local usage.
4. A fourth method is to construct and estimate a small engineering-economics process model of the local exchange network. Rather than select a best technology from a variety of feasible choices, the model summarizes in a set of technical and cost equations the results of telephone company investment and operations practices that are themselves derived from more detailed engineering planning models. This approach, which we use in this study, is effective in representing the major factors that determine incremental costs without requiring highly detailed data. We develop such a model to estimate the average incremental costs of supplying an increased level of services for a specified set of demand and community conditions.

Local conditions—including distance from the central office switch, population density and growth, and telephone calling rates—vary widely across California communities. Rather than attempt to

[2]Examples of such models are BellCore's feeder planning model (EFRAP) and the switching costs models from GTE (COSTMOD) and BellCore (SCIS).

estimate a statewide average level of incremental costs, we report illustrative estimates for a range of typical community conditions. The values obtained represent levels of incremental cost experienced by California operating companies, but they are not estimates for particular markets nor are they intended to be used in regulatory rate proceedings.

THE CONCEPT OF INCREMENTAL COSTS

Incremental costs are the difference in the total costs of the firm in two situations—a baseline scenario and an alternative scenario. Compared with the baseline, the alternative scenario includes an output increment and a corresponding cost increment.

Figure 2 illustrates four types of scenarios. It emphasizes the output increment as a function of time. In each case, the baseline scenario is shown by a solid line and the alternative by a dashed line.

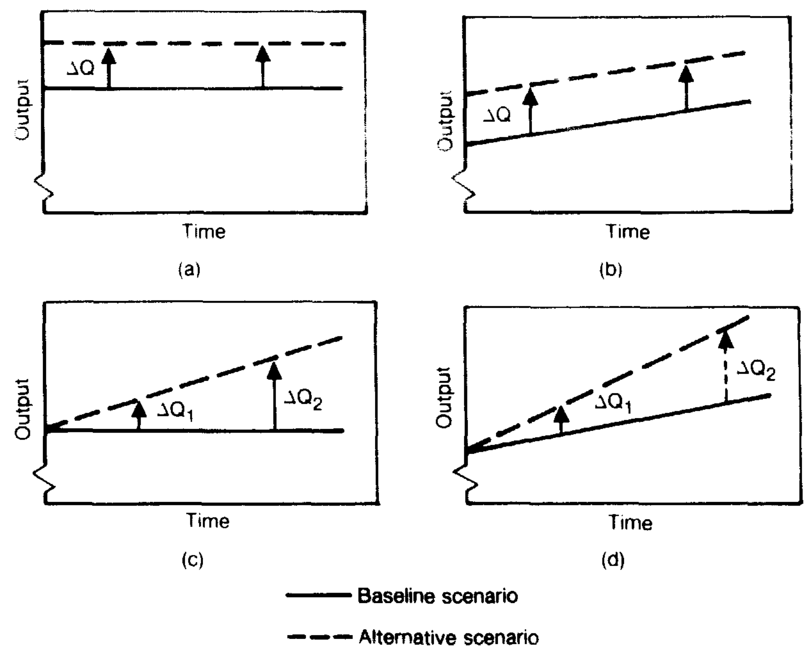


Fig. 2—The output increment

a. Baseline output is constant over time, and the alternative is a higher, constant level of output. This is effectively a timeless, static market.
b. The baseline output is growing, and the alternative is a permanently higher level of output growing at the same rate.
c. The baseline is constant output, and the alternative scenario is growing output.
d. The baseline is growing output, and the alternative is a higher rate of growth.

The cost increment in each case includes future as well as current investments and operating expenses. Figure 3 illustrates the cost increments that could be associated with cases (a) and (b) on the assumption that capital is divisible and can be expanded in small increments at constant cost.

When capital equipment is lumpy and durable, the increment in investment required for an alternative scenario depends on the relationship of output to available capacity. Figure 4 illustrates this. If there is sufficient excess capacity in the baseline scenario, a small output increment requires no immediate investment. If the alternative scenario is a higher, constant output level (case a) that can be accommodated by the baseline capacity, incremental costs consist only of the additional operating expenses in each period. However, if the alternative output level exceeds the available capacity, the cost increment includes the additional lump of capital plus operating expenses.

When the baseline scenario is one of continually growing output (case b), the firm must eventually expand lumpy capacity to meet the baseline demand. The bottom panel of Fig. 4 shows a solid-line step-function of periodic additions to capacity and a corresponding step-function of increases in investment that is imposed on a steady growth in operating expenses. In this case, the higher level of output in the alternative scenario, shown by the dashed lines, requires that capacity be increased sooner.

In cases (a) and (b) there is a permanent increase in the level of output. In effect, the investment in additional capacity makes possible a constant flow of additional output, indefinitely. In cases (c) and (d) (not shown in Figs. 3 and 4), the increase in output itself grows over time.

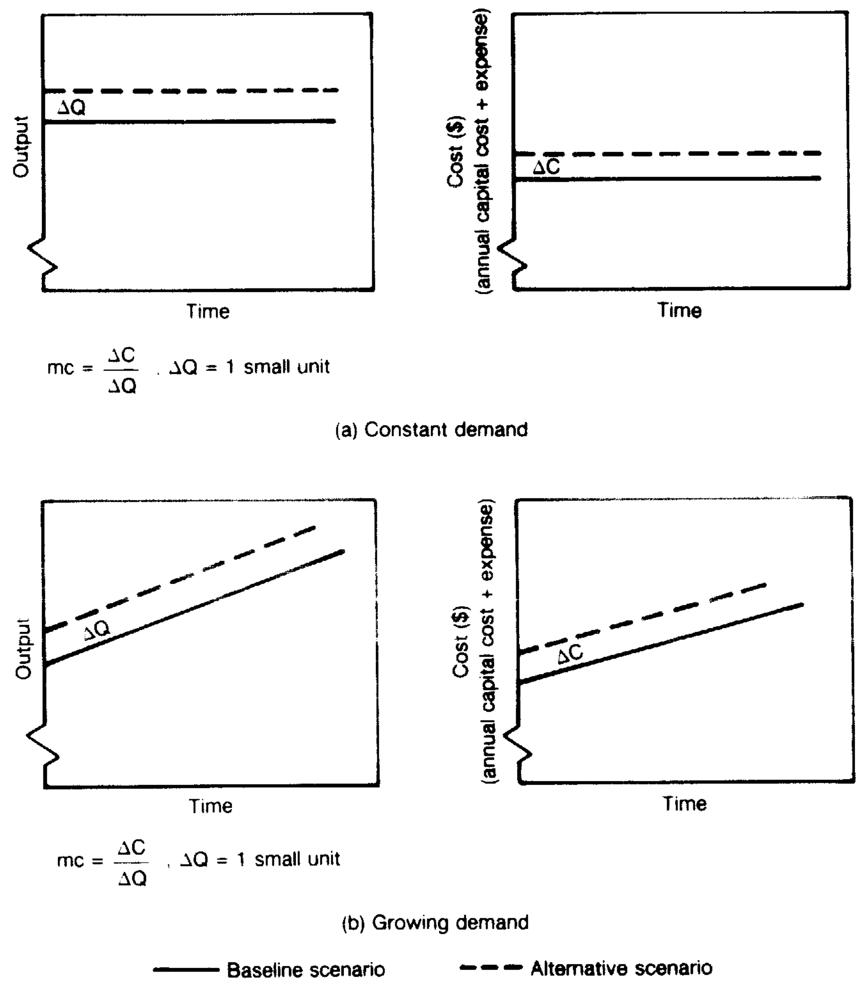
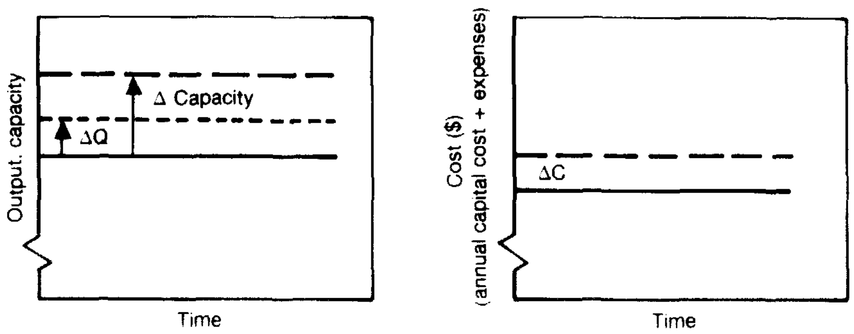


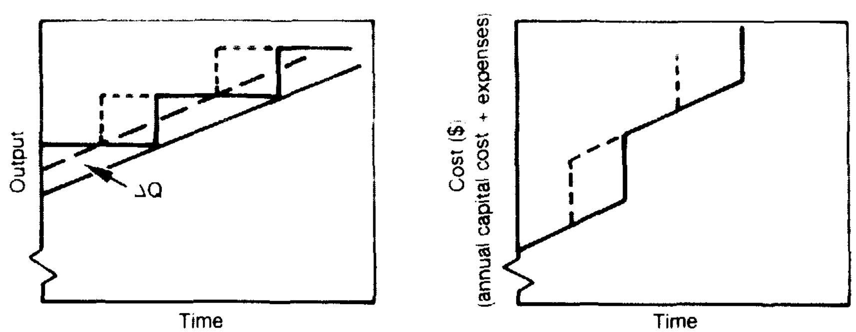
Fig. 3—Smooth capital



$mc = \frac{\Delta C}{\Delta Q}$ large, if capacity fully used (shown)
expenses only, if excess capacity (not shown)

$AIC = \frac{\Delta C}{\Delta \text{ Capacity}}$

(a) Constant demand



Δ PV cost = PV dotted cost stream − PV solid cost stream

$mc = \frac{\Delta \text{ PV cost}}{\Delta Q}$

$AIC = \frac{\Delta C}{\Delta \text{ Capacity}}$

(b) Growing demand

Fig. 4—Lumpy capital

Marginal Cost

The output of a service is normally measured as a flow of services over a period of time, which we take to be one year. The total costs of one year's output include the annual charges for the use of capital during the year plus one year of operating expenses.

We will assume that the increased flow of output in the alternative scenario is permanent. The firm's marginal cost is then the change in total cost per unit increase in the rate of output (the partial derivative of the total-cost function with respect to output). When the unit of output is relatively small, marginal cost is effectively the change in total cost of permanently increasing output by one unit.

When baseline output is constant over time and capital is lumpy (Fig. 4a), the value of marginal cost varies with the rate of capacity utilization. When there is excess capacity, marginal cost is approximately per-unit operating cost, but when capacity is fully utilized, marginal cost also includes the annual charge for the full investment cost of a lump of capacity.

When baseline output is growing over time and capital is lumpy (Fig. 4b), an increase in output accelerates the dates for expanding capacity. Under the baseline scenario of growing output, the firm periodically invests in increased capacity; under the alternative scenario, it makes these investments sooner. The discounted present value of the difference of these two investment and expense streams constitutes the additional current cost to the firm of the increased output. The marginal cost is then the annualized value of this amount, per unit of increased output.

Marginal cost in the growing-output, lumpy capital case will vary according to the specific circumstances in a local exchange—the current level of capacity utilization, the rate of output growth, and the size of the investment lump. When an increase in output affects construction schedules only many years later, the discounted difference in costs is low. Marginal cost is highest when added output requires immediate construction that would otherwise be undertaken somewhat later.

Average Incremental Costs

For this study we use *average incremental costs* (AIC) as a central measure of the additional costs of greater telephone services. We define average incremental costs as the additional annualized investment cost of a lump of capacity divided by the effective quantity of output made possible by that additional capacity, plus the per-unit operating expenses:

$$AIC = \frac{\text{annualized investment cost of 1 lump of capacity}}{\text{effective capacity}} + \text{per-unit operating expenses}$$

Effective capacity is measured as the maximum output obtainable from one lump of capacity under normal engineering practices, which provide a reserve for technical failures and unexpected increases in demand.

Other research in this project investigates the efficiency of alternative pricing rules as they relate to different measures of incremental costs. That work (Park, 1989, 1990) establishes that when prices are to be the same across conditions of varying capacity utilization, average incremental costs provide a relatively efficient basis for setting prices. AIC can therefore be thought of as a proxy for marginal costs when capital is lumpy.

Incremental Cost Tests

To assess whether the production of an entire service (for example, residential exchange access and local calling) is desirable, or whether it is receiving a subsidy, an *incremental cost test* (Faulhaber, 1975; Sharkey, 1982) can be used to compare the additional costs of the entire service with the revenues from that service.

Two separate calculations, with and without the service in question, are made: First, one would find the minimum-cost method of producing both that service and the other services. Second, one would calculate the minimum-cost method of producing only the other services. The difference in costs would be the incremental cost of the service being tested.

The estimates in this study, however, are of the average incremental costs of expanding the quantity of local exchange service for an already-established firm currently supplying service to a community of subscribers, rather than the costs of initially establishing the service. These estimates cannot therefore be directly used in such incremental cost tests.

What Is Fixed, What Is Incremental?

The total costs of providing telephone service include all of the investment, operating expenses, and overhead expenses of the firm. Which elements of those costs are incremental depends on the situation. At one extreme, if the firm is not yet established, all costs must

be incurred to provide an initial quantity of service. In contrast, for an established firm, the incremental costs of expanding an existing service are just the additional costs necessary. The development of a new service may be an intermediate case, requiring startup investment and expenses that do not recur when service is later expanded.

In this study we examine the average incremental costs of an existing, established local telephone company that is already supplying local service. The relevant market is the local community, and the major investments undertaken to establish telephone service are a fixed cost. Additional output is produced with lumpy investment at the intensive margin, by adding additional subscribers to the existing distribution plant and by increasing the number of calls made by existing subscribers.

To estimate average incremental costs we specify typical values of the major community characteristics affecting local telephone network construction and operation. These characteristics implicitly determine the firm's situation. Thus, in a slowly growing community the capacity of structures (conduit and telephone poles) supporting the feeder cables will accommodate 15 or more years of growth, and we therefore assume that the cost of structures is fixed. In medium and high growth areas, structures must be reinforced, and we include these added costs in average incremental costs per line.

ROADMAP

Our objective is to estimate the incremental costs of access to the telephone network, the incremental costs of local usage, and also those costs that are effectively fixed. We first determine (in Secs. II, III, and IV) the incremental capital costs in each of the three functional components of the local exchange—the local loop, the local switch, and interoffice transport. In addition, we determine (in Sec. V) changes in operating expenses due to increases in service.

These estimates then enable us (in Sec. VI) to fill in entries in a table similar to Table 2. Additional access to the network will impose extra costs in the local loop and at the switch. Increased network usage at peak hours will increase costs at the switch and for transport between local switches, with costs depending on both the number of call attempts and the duration of those calls.

Actual values of incremental capital costs depend on major characteristics of the local community and telephone subscribers. We examine these costs for three kinds of communities—small urban areas, communities of approximately average California characteristics, and

Table 2

ILLUSTRATIVE TABLE OF INCREMENTAL COSTS OF LOCAL EXCHANGE SERVICE

Access—per line	
Loop	—
Switch	—
Total	—
Usage—per minute in busy-hour	
Switch	—
Interoffice transport	—
Total	—
Usage—per attempt in busy-hour	
Fixed cost	

larger urban areas. In each community, we also estimate incremental costs of local service to an average residential subscriber and an average business subscriber.

In Sec. VII we extend the model of the local exchange carrier's network to include the additional switching required to place calls to neighboring communities.

Local exchange carriers supply a wide variety of services in addition to network access and local calls. In Sec. VIII we investigate the technologies used for four types of services and discuss sources for data suitable for estimating incremental costs.

II. LOCAL LOOP

A local loop is a pair of wires (or an equivalent voice channel) connecting a particular subscriber to the central switching point of the local telephone network. Along the route to the central office, the twisted pair is successively bundled together with the pairs of other subscribers, until, by the time the wires reach the wire center where they connect to a switch, hundreds of wire pairs are contained within a single cable.

STYLIZED TECHNOLOGY

The trunk-and-branches nature of the local loop (Fig. 1) results in quite different engineering conditions for the feeder and the distribution portions of the loop. In a growing community, the feeder system requires regular increases in capacity.

Typically, feeder cables leave the wire center in four directions (north, south, east, west). Each feeder cable route consists of a series of feeder segments—one or more feeder cables, several hundred feet or more in length—that terminate in a splice or cross-connect device located in a manhole or pedestal. The cables are placed in conduits (in the case of underground construction) or attached to poles (for aerial construction).

At intermediate points along the route, and at the end of the feeder cable, the cable pairs are cross-connected to smaller cables that distribute telephone service to subscribers at the ends of the loops.

Each feeder segment is engineered separately, taking into account the currently available capacity, predicted rate of growth, and construction costs of adding cable. The cable itself is available in a wide range of sizes, from 25 pairs to 3,600 pairs. Feeder segments normally use cable sizes from 400 to 3,000 pairs.

When a feeder segment nears full utilization and must be relieved, the size of cable to install is calculated to minimize the present value of current and future investment and installation costs, taking into account economies of scale in cable size, startup costs of an installation job, and implicitly, the opportunity costs of using up space in the supporting duct or pole structure. The engineering choices result in larger cable sizes for higher-growth segments. In addition, a larger cable is installed when the capacity of its supporting structures is nearly exhausted, to postpone the date at which additional structural investment will be required.

As the distance from the wire center along the feeder route increases, the number of pairs diminishes to those required to serve the more distant customers. The largest feeders are usually installed in segments closest to the wire center, with sizes tapering off at increasing distance.

Distribution cable constitutes the "last mile" of the local loop. It is engineered differently from feeder segments, reflecting the importance of the startup costs of installing cable at smaller sizes. Distribution cables and structures are sized to provide enough capacity to serve the *maximum* subscriber demand for lines in the neighborhood or serving area supplied from the feeder termination point.

Cables of the smallest wire diameter (26 gauge) are used for local loops up to about three miles in total length (feeder plus distribution). Longer loops must include segments with larger diameter wires, to limit the circuit's total electrical resistance.

COST FUNCTION

For a given set of community parameters, the local loop portion of the process model calculates incremental feeder investment, incremental structure investment, and distribution investment.

Incremental feeder investment occurs on a regular basis in growing communities. When an individual feeder segment approaches the designed utilization rate, it is relieved by adding additional cable.

Additional structures (poles, conduit, manholes, and associated equipment) are required when continued growth eventually exhausts available structure capacity. Structures are engineered to have sufficient capacity to satisfy projected growth for at least 10–15 years. In moderate- and fast-growing areas, additional lines require expanding structures (or using larger cable sizes or carrier systems), so that this cost is also incremental. At lower growth rates, however, a structure may effectively never be exhausted, and in these cases we consider it a component of fixed cost.

Nearly all of the investment in the *distribution* segments of the local loop—both cable and supporting structures—is incurred when a distribution area is first wired. These initial investments are designed to have sufficient capacity to accommodate all projected growth in the neighborhood or serving area; no additional construction is anticipated when additional subscriber lines are added. We assume that when the number of lines increases in an already-wired area, the investment costs of the distribution system are fixed.

To calculate the AIC of additional feeder capacity, we increase capacity by the size of the largest feeder cable in use, calculate the additional investment required, and divide by the increase in the effective number of lines.[1] This investment cost, including periodic replacement based on economic lives of broad outside plant categories, is then stated on an annual basis.

AIC for the local loop are obtained from the following equations, in which "f" represents separate functions:

$$
\begin{aligned}
\text{Cable size} &= \text{f(growth rate, construction type)}\\
\text{Gauge mix} &= \text{f(average loop length)}\\
\text{Feeder investment} = \text{FI} &= \Sigma_{\text{gauges}}\, \text{f(cost\_per\_foot} \times \text{length, economic life)}\\
\text{Structure investment} = \text{SI} &= \text{f(construction type, length, economic life)}\\
\text{Effective capacity} = \text{EC} &= \text{f(cable size, designed fill, restricted pairs)}\\
\text{Maintenance expense} = \text{ME} &= \text{f(construction type, length)}\\
\text{Annual factor} = \alpha &= \text{f(cost of capital, economic life)}\\
\text{AIC} &= \alpha \times \text{FI/EC} + \text{ME, if low growth}\\
&= \alpha \times \text{(FI + SI)/EC} + \text{ME, if medium or high growth}
\end{aligned}
$$

The major inputs for these equations are summarized in the following paragraphs. The detailed equation specifications are contained in the spreadsheet in Appendix C.

Average Loop Length

The length of a particular subscriber's local loop depends directly on his or her geographic location in relation to the central office. The average length of all subscribers' loops in a community will reflect the local population distribution. In planning for long-term growth, the local exchange carrier attempts to locate wire centers centrally and to add new switching nodes when the costs of longer loops outweigh the investment in new central switches.

Across California communities, the average length of local loops varies greatly. The outside plant accounts of GTE and Pacific Bell and a stratified sample of wire centers provide the statistics summarized in Table 3. The typical 9,500-foot average feeder cable varies by a factor of five across a sample of wire centers. The average distribution cable, which is typically 1,700 feet, may exceed 6,000 feet in some communities.

In most areas, business subscribers are located closer to the center of a community than residential subscribers are and, on average, are

[1]We do not explicitly model the tapering of feeder cable size with distance. Sample calculations indicate that tapering has only a modest effect on our AIC estimate.

Table 3

AVERAGE LOOP LENGTHS IN CALIFORNIA WIRE CENTERS
(In feet)

Customer/Cable Type	Short	10%	Average	90%	Long
Residence and business					
Feeder	2,800	6,600	9,500	12,500	15,000
Distribution	500	700	1,700	3,000	6,500
Residence					
Feeder	5,700	8,000	10,200	13,000	17,000
Distribution	600	900	1,900	3,500	7,500
Business					
Feeder	1,900	4,000	8,900	12,000	13,300
Distribution	300	600	1,500	2,500	6,500

SOURCE: Pacific Bell and GTE loop studies, 1986.
NOTE: Approximately 80% of the wire centers observed in a sample of California wire centers had loop lengths between the 10% and 90% percentile values shown.

served by both shorter feeder and shorter distribution cables. Again, business loop lengths vary greatly across different communities.

Wire centers in more densely populated areas (a high ratio of telephone subscribers per square mile) tend to have somewhat shorter average loop lengths. However, the variation in average loop length within wire centers of similar density is substantial. Some urban wire centers have quite long average loops; other wire centers in low density areas have short loops.

Cable Size

Cable size depends on the growth rate of lines and the type of construction. We classified model communities as low growth (< 500 lines/year), medium growth (500 to 2,000), and high growth (> 2,000); and as low density (< 400 lines/square mile), medium density (400 to 2,500), and high density (> 2500). From engineering cable sizing guidelines we established the typical cable sizes shown in Table 4. Feeder cables are placed in underground conduit or attached to telephone poles. Distribution cable is attached to poles or buried directly in the earth.

Gauge Mix

Up to a distance of about three miles, a local loop can consist entirely of 26-gauge cable. Beyond that point longer loops must have larger diameter pairs to limit their total electrical resistance. Each additional 100 feet of total length requires approximately 300 feet of 24-gauge cable (and thus 200 feet less 26-gauge cable) to satisfy the resistance constraint.

Table 4

TYPICAL INSTALLED COST OF CABLE
(In dollars per cable foot)

	Feeder Cable Construction			
	In Underground Conduit		Aerial	
Growth Rate	No. of Pairs	Cost	No. of Pairs	Cost
Low	600	$12-$15	600	$20-$24
Medium	1800	$25-$30	1500	$42-$45
High	3000	$45-$55	1800	$45-$48
	Distribution Cable Construction			
	Buried		Aerial	
Density	No. of Pairs	Cost	No. of Pairs	Cost
Low	100	$9-$10	100	$6-$7
Medium	200	$12-$13	200	$9-$10
High	400	$18-$19	400	$14-$15

SOURCE: Pacific Bell, GTE broad-gauge cost studies.

We approximate the effect of longer loop length on cable gauge by assuming that beyond a minimum distance (one mile) the distances of subscribers from the wire center are uniformly distributed. Then, given the average loop length, we calculate the proportion of 24-gauge and 26-gauge cables and the average lengths of each.

Structural Investment

Underground conduit and manholes typically can hold some 20–40 feeder cables, and poles can generally support up to six cables. In fast-growing areas, this capacity is eventually exhausted, and reinforcement of cable structures can require large investments, especially in higher-density urban areas. Cable engineering decisions recognize this opportunity cost. As *structure* utilization approaches capacity, larger cable sizes are installed. In addition, existing cables may be replaced with larger sizes, and carrier systems (which combine a number of subscriber circuits onto a smaller number of pairs) may be introduced.

The costs of building new structures vary greatly, according to local community conditions, size of conduit, and size of cable. We use a single factor for structural investment for each type of construction and do not attempt to relate variations to local conditions. Using California experience, we assume that structural investment is 40 percent of underground cable investment and 20 percent of aerial cable investment. These factors represent the incremental cost of either actually expanding the structure, or the cost of using higher-capacity cable systems in existing structures.

Effective Capacity

Feeder cable construction is planned so that the increment in the capacity of a segment becomes available when projected demand reaches a designed percentage of current capacity. This "designed fill," typically 85 percent, includes a margin for variations in demand growth and slippage in construction schedule. Immediately after construction is completed, the percentage utilization of the feeder segment drops to its minimum value. Then, over time, growing demand will raise utilization. The average fill will be achieved at some time between completion of the addition and the reinforcement of segment once again.

Figure 5 shows the projected growth in demand, the addition of capacity at year *t*, and the corresponding utilization rates as demand continues to grow until capacity is again increased.

Because feeder segments are expanded at different times, and with different cable sizes, at a given moment some cable pairs cannot be connected all the way from a subscriber to the central office. These "restricted pairs," averaging some 10 percent of the pairs in a given segment, reduce the effective capacity.

Periodic Replacement

We provide for periodic replacement of capital equipment by assuming that assets are replaced at the end of their economic lives with identical equipment having the same real investment cost. We use economic lives of 17 years (for aerial construction) and 20 years (for underground and buried construction), poles 30 years, and conduit 50 years. These lifetimes are based on operating experience and projections in California.

Annualization

We convert capital investments to a levelized annual cost by using a 15 percent annualization factor. This rate incorporates the typical real

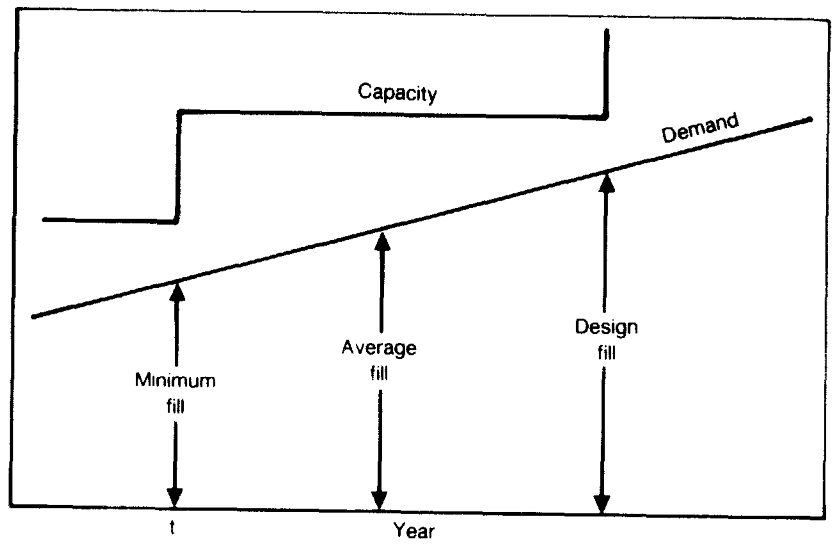


Fig. 5—Feeder cable utilization

cost of capital to a California local exchange company with a representative mix of debt and equity. It includes corporate income taxes and excludes inflation.[2]

The annual factor applied to each category of investment combines the 15 percent annual cost of capital and the effect of replacing the investment periodically at its economic lifetime.

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[2]Omitting the tax effect of accelerated depreciation, consider a local exchange carrier with 40 percent debt *(d)* at a 9.25% interest nominal rate *(i)* and a 13 percent nominal return on equity *(r)*, with combined corporate and property tax rate of 50 percent *(t)*. The carrier has a cost of money of

$$\text{COM} = d \times i + (1 - d) \times r = 11.5 \text{ percent}$$

To yield this cost of money, the firm must earn a nominal return on new investment, before taxes, of

$$\text{RIT} = (1 - d) \times r/(1 - t) + d \times i = 19.3 \text{ percent}$$

At a 3 percent rate of inflation, the real before-tax return (RIT) is 14.5 percent.

Maintenance

Maintenance of local exchange equipment is a never-ending process, one that is largely independent of the rate of use. Particularly in the local loop, the adverse effects of weather and construction activities require continuing expenditure to repair feeder and distribution cables and associated facilities.

The work of maintenance personnel includes both repair tasks and rearrangements of facilities that are occasioned by customer moves and uneven patterns of growth. Annual expenditures are segregated into repair accounts and move accounts, classified by type of facility and type of construction.

To estimate the increment in annual maintenance costs of the local loop due to an increase in access lines we relate the repair account costs to cable length as a measure of the exposure of feeder and distribution cables to damage and deterioration. For conduit and poles we apply a maintenance factor to original investment. We apply these factors to the increase in the number of cable pairs and the associated increase in investment in supporting structures. The estimates are shown in Table 5.

RESULTS

We characterize conditions in a community in terms of the following model community parameters that affect the local loop:

Growth	Number of lines per year
Density	Number of lines per square mile
Feeder cable length	Feet
Feeder construction	Percentage underground
Distribution cable length	Feet
Distribution construction . .	Percentage buried

The results of local loop calculations for three sets of model community parameters—type of construction, rate of growth, density, and average loop length—are shown in Table 6. From an examination of results from these calculations as well as similar calculations for other model community parameters, these general findings emerge:

- Average incremental costs are nearly proportional to loop length, increasing at a faster rate at longer lengths that require smaller-gauge wire. Over the range of average lengths in California communities, incremental costs can vary by as much as 200 percent.

Table 5

LOCAL LOOP MAINTENANCE COSTS

Type of Facility	Annual Maintenance Cost
Underground feeder	\$1–2 per pair-mile
Aerial feeder	\$6–\$8 per pair-mile
Aerial distribution	\$6–\$8 per pair-mile
Buried distribution	\$10–\$16 per pair-mile
Conduit	0.3–0.5% per \$ investment
Poles	0.6–0.8% per \$ investment

NOTE: Underground loops are placed in conduits; buried loops are in earth trenches.

Table 6

LOCAL LOOP: AVERAGE INCREMENTAL COSTS AND FIXED COSTS
(Dollars per year per loop)

Community	Average Incremental Capital Cost	Maintenance Expense	Fixed Cost
Small urban 16,000 ft aerial loop, low growth, low density	104	15 120	164
Average 12,000 ft underground loop, medium growth, high density	42	2–4	60
Larger urban 8,000 ft underground loop, high growth, high density	29	1–3	45

NOTE: At 1988 prices.

- Because of larger cable sizes, communities with rapid line growth have somewhat lower average incremental costs per line than areas with low growth.
- Aerial construction in the feeder system substantially raises the incremental cost of adding lines.
- Loop lengths and average incremental costs vary a good deal across communities of similar density. Although loops are on average shorter in larger urban areas, average incremental costs in some high-density areas exceed those in other suburban areas.

- Local loops have substantial fixed costs, consisting of the final sections of cable that distribute service to subscribers and the poles and buried structures that support them. In slowly growing communities, feeder structures are an additional fixed cost. On a per-line basis, fixed costs exceed the average incremental costs of one loop.

III. LOCAL SWITCH

The technology of switching local telephone calls has evolved from the use of operator cordboards and electromechanical stepping machines to stored-program control electronic computers. The local network continues to carry a mixture of analog and digital signals—employing analog transmission on the local loops connected to subscribers' telephone sets, digital switching of calls, and digital transmission of calls between central offices.

Today, although many analog switches are still in service at the local level, digital switches are the dominant technology used to expand and replace local switches. California local exchange companies purchase digital switches from three major vendors.

In modeling local switching costs, we consider only digital switches connected to local loops which carry analog signals. If subscriber equipment is eventually replaced with instruments that transmit digital signals (a necessary step in the establishment of an integrated services digital network—ISDN) copper pairs or fiberoptic cables will carry digital signals over the local loop to the local switch. This technology would lower the cost of terminating lines at the switch, but the higher costs of subscriber terminal equipment make it currently unattractive.

Calls between central offices that house the local switches are electronically bundled and travel over large-capacity interoffice trunk transmission facilities on a variety of metallic, fiberoptic, and radio systems. Although local exchange carriers use both analog and digital technologies to transmit this traffic today, almost all newly installed systems are digital. Our model therefore assumes digital interoffice transmission.

STYLIZED TECHNOLOGY

A central office switch functions to supervise subscribers' telephone lines, establish a connection between two lines for each call, supply a variety of special features (e.g. call forwarding, call waiting), and perform associated billing, maintenance, and other services. A digital switch, shown in block form in Fig. 6, is composed of three basic functional components—peripheral equipment, the switch matrix, and common control.

The *peripheral equipment* connects subscriber lines to the switching network. Other peripheral equipment connects the switch, through the